Physeal Injuries
Basic Principles

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A. Anatomic Considerations

1. Basic Principles
   a. The Tissue Bone
      1) A rigid matrix, which will not expand.
      2) All growth and remodeling of bone tissue must be on the surface (appositional ossification).
   b. The Organ Bone (i.e., humerus, femur).
      1) Needs to grow in length.
      2) A distensible matrix (cartilage) is interposed at the ends to allow linear growth.
      3) This cartilage matrix after it grows and expands is reabsorbed and replaced by bone (endochondral ossification).

2. Blood Supply (40,41)
   a. Dangerous Side – Epiphysis
      1) Nutrition of physeal proliferating cells comes from the epiphyseal vessels.
      2) If these are injured, growth may be impaired. (Fig. 1)

Figure 1. Dangerous Side. Injury to the vessels on the epiphyseal side results in growth disturbance (arrow).

b. Safe Side - Metaphysis
   1) Metaphyseal and diaphyseal vessels reabsorb degenerative calcified cartilage and serve as source of osteocytes producing the primary spongiosa.
   2) If these vessels are injured, the reabsorption of cartilage may be impaired, but with new vessel invasion reabsorption and new ossification will resume (Fig. 2).
Figure 2 Safe Side. Injury to the metaphyseal side results in continued growth of the physis but with no reabsorption of the degenerative calcified cartilage. As a result the phyleal line widens (arrow) until new vessels invade the metaphysis to reabsorb the degenerative cartilage and reinitiate ossification.

3. Incidence
   a. Overall incidence varies from 14 (6a) to 28% (22a).
   b. Originally it was felt that grade school athletes would experience a large number of crippling physeal injuries and thus contact sports in this age group were to be avoided.
   b. Subsequent follow-up studies have demonstrated a very low incidence of physeal injuries in organized (i.e., Pop Warner, Little League, contact sport events).
   c. Most of physeal injuries occur towards the end of skeletal maturity (32)
      1) Females peak age 11-12 years.
      2) Males peak age 13-14 years.
      3) Increased risk at this age due to:
         a) Weakening of perichondrial ring at end of growth.
         b) Increased body size (mass) plus higher velocity of sporting activities produces greater Kinetic Energy
            \[ KE = MV^2. \]
      4) Exception: Physeal injuries about elbow occur earlier.
   d. The distal radius is the most common physis injured followed by the distal tibia and the finger phalanges. (TABLE I).
   e. Most of the fractures of the distal tibial physes occur in adolescent athletes (12)

4. Structural Factors
   a. Mammillary Processes
      1) Projections of weight bearing physes which stabilizes them against shear stresses.
      2) Most prominent in the distal and proximal femur (Fig.3)
3) In injuries with shear forces, the growth cells on these processes are sheared off which is a factor in the high incidence of growth arrest with distal femoral physeal injuries.

b. Physis fails more readily in torsion than tension (22,26)

c. The role of compression is unknown (29).

B. Classification of Physeal Fractures

1. **Poland** was the first to classify physeal injuries in his book published in 1898 entitled *Traumatic Separation of the Epiphysis* (35).
   a. This was before the advent of X–rays
   b. His classification was based of autopsy and surgical specimens.

2. One of the most extensive works on this classification of physeal fractures was published in Stockholm, Sweden by Bergenfeldt (1a)
   a. Based on 295 cases in 9-year period.
   b. Recognized 6 different patterns with the incidence of each pattern (Fig.4).

![Figure 4 Bergenfeldt’s Classification](image)

3. Following this many other reports appeared in the literature mostly modifying Bergenfeldt’s original classification.
4. The classification that has gained the widest acceptance has been the original five types reported by Salter and Harris in 1963 (37).
   a. A sixth type was later added by Rang in 1969 (36a) (Fig. 5).

5. Probably the most all-encompassing classification was that described in 1981 by Ogden
   a. This classification included 9 types and 11 subtypes (20 total) (Fig. 6).

6. The most recent classification proposed is that by Peterson in 1994 (31a) (Fig 7).
a. He disputed the existence of the Salter Harris Type V arrest injury.
b. The main contribution of his classification has been the recognition of the metaphyseal fractures (Type I) causing a growth arrest (Fig, 8).

8. What is the significance of the classifications????
   a. They originally were thought to be PROGNOSTIC.
   b. They are probably are more DESCRIPTIC.

C. Physeal Arrest
   1. Basic Pathology.
      a. Location of fracture line.
1) Classically taught that the fracture line was through the zone of hypertrophy.
2) Recent studies show location of line varies, can be anywhere through the physis.
b. Osseous bridge develops which becomes dense cortical bone (secondary to tension stress from peripheral viable physis? (Fig. 9).

Figure 9 Osseous Bridge Structure
A., Plain x-rays demonstrating the sclerotic bone of the osseous bridge (arrow). B. Histopath specimen demonstrating that the bridge is cortical bone (circle).

2. Patterns of Arrest
   a. Ogden (29) and Bright (2) have divided the closure patterns into three types:
      1) **Central** Bridges
         (Ogden Type III, Bright Type II) [FIGURE 1]. The bridge is central and surrounded by a normal physeal plate (Fig. 10)
Figure 10 Central Bridge A. Line drawing demonstrating the location of the bridge X-ray shows sclerotic central bridge (circle). The physis has migrated vertically (lines).

2) **Peripheral** Bridge
   (Ogden Type I, Bright Type I. Involves the perichondral ring at the periphery (Fig. 11).

Figure 11. Peripheral Bridge. A. Line drawing showing the peripheral location of the bridge. 
B. The peripheral location of the bridges in both the femur and tibia (circles) have created a severe angular deformity

3) **Linear**
   (Ogden Type II, Bright Type III) [FIGURE 3]. Common after Salter-Harris Type IV injuries. Transverses from cortex to cortex (Fig. 12).

Figure 12. Linear Bridge. A. Line drawing showing the location of the linear bridge. 
B. X-ray showing the slightly off center linear bridge (arrow). The original injury was a Type IV physeal injury.
b. Peterson (31b) uses the descriptive nomenclature of: Linear, Central, Peripheral.
   1) This author prefers this nomenclature as it is more descriptive.

3. What are the benefits of a classification of osseous bridges??
   a. Location affects the surgical approach.
   b. Location affects the type of deformity.
   c. Location affects the success of resection.

C. Treatment: Basic Concepts
   1. Introduction

   a. Treatment of partial physeal arrest has enjoyed great popularity since the pioneer work of osseous bridge resection in the 50's by Key and Fort(17), followed by the clinical use of osseous bridge resection in patients by Osterman and Langensiold (19,20,21,30,31) in the late 1960's and early 1970's. As a result, osseous bridge resection has become a standard method of treatment of partial growth arrest.

   b. Early in the development of this procedure it was felt that often osseous bridge resection would automatically restore normal growth.

   c. In the past decade numerous series have been reported using various interpositional substances. The results of these series have not always been consistently excellent, As a result criteria for successful treatment are now becoming better defined.

   d. To determine the possible success of osseous bridge resection, five questions must be answered:
      1) Is there a partial growth arrest?
      2) Where is the arrest?
      3) Will resection help?
      4) Are there alternatives to resection?
      5) What if the arrest recurs?

   QUESTION 1: Is there partial arrest?

   a. Late when there is an obvious sclerotic osseous bridge with a secondary deformity, the presence of a partial growth arrest is apparent.
1) But full recovery may not be achievable once secondary changes occur.
2) The success to a good outcome is early reversal of the changes prior to the onset of the deformity.

b. Early diagnostic aids for detecting an early physeal arrest.
1) Plain Radiographs
   a) Physeal Narrowing
   b) Sclerotic bone (reaction to tension forces)
   c) Absence of migration of Harris Park Growth Arrest lines.
2) Differential radionucleotide scans
   a) May be helpful late.
   b) Early, there may be increased activity due to the development of sclerotic bone.
   c) About the knee, cross sectional mapping of the physis may be useful using special apex views (14).
   d) This procedure is still not widely used enough to produce data to confirm it's efficacy.
3) CT Scans (9,33,36)
   a) Useful more in central lesions.
   b) Requires very thin sections.
   c) Gives a good idea of the cross sectional extent of bridge.
   d) With newer machines, sagittal and coronal reconstructions are helpful in determining the extent of the bridge.
4) MR imaging(15, 16, 38)
   a) Early studies have demonstrated the presence of defects in the physis prior to ossification, (i.e., fibrous bridges).
   b) MRI also useful in following progression of growth arrest lines.
   c) Experience with this type of diagnostic study is still quite limited and its role has not been definitely determined as yet.
5) Once an osseous bridge is established, the simpler way to map out the extent of the lesion is with polytomography. Carlson and Wenger(6), have purposed a simple grid method to determine the extent and location of the arrest.

**QUESTION 2:** Where is the physeal arrest?

a. See previous section (B-2) on classification of arrest patterns by Bright and Ogden.
b. Does the location of the arrest have any affect on subsequent deformity?
   1) Central - Volcano effect. The peripheral physis may continue longitudinal growth. Less angular deformity,
   2) Peripheral bars - Produces the severest angular deformities.
   3) Linear - Produces combined shortening and angular deformities.

c. Location also affects surgical approach.
   1) Central - Requires large metaphyseal window.
   2) Peripheral approach directly.
   3) Linear - Approach via an osseous tunnel through the metaphysis from cortex to cortex.

d. Does location affect success of resection?
   1) Central and linear both have normal peripheral physis to create symmetrical growth.
   2) Peripheral bridges may persist with asymmetrical growth because of lack of viable physis peripheral of the resection area.
      a) Two series(3, 39) where the location of the bar was designated had to poorest results with peripheral bridges.

QUESTION 3: Will resection of partial growth arrest help?

a. Reported series show variable success [SEE TABLE 2]

b. What factor seems to contribute to success?
   1) The most consistent factor appears to be the size of the bridge.
      a) Bridges >50% of the physis universally have poor results.
      b) The smaller the lesion the better success.
   2) Age: Younger patients have more potential for growth. There needs to be at least two years of growth remaining to achieve satisfactory results.
   3) Duration since injury: Greater than two years since injury often produces poorer results.
   4) Etiology: Best results with trauma, poorest with infection and radiations etiologies.
   5) Ideal Candidate: Young, small bridge, trauma origin, recent onset, central or linear bridge.
      Poor Candidate: Older, larger bridge, infectious or radiation origin, peripheral bridge.

c. Does the nature of the interposition material affect the outcome?
1) Experimentally, it has been shown that load sharing (solid) interpositional material (silastic, polymethylmethacrylate) provided protection to the peripheral physis, thus preventing further injury (4). Thus, the solid materials may provide some protection to remaining physis over fat.

2) There is not enough clinical data, at this point, however, to make comparisons between the success of the various interpositional materials, (i.e., silastic, fat and PMMA).

QUESTION 4: Are there alternatives to resection?

a. Physeal distraction has been used with limited success in older individuals where there is a needs for both correction of the deformity and length discrepancy (7, 10, 30)

b. Because of the unpredictability of continued growth after distraction, this procedure is usually limited to those patients at the termination of growth where a single procedure can correct both the length and angular deformities.

QUESTION 5: Can a Recurrence be re-resected with success?

a. Yes, as long as they still meet the original criteria for resection, (i.e., at least two years remaining growth < 50% of the physis involved.

b. Partial arrest in a very young individual may require an aggressive approach of repeated resections to maintain continued growth.

D. Technical Points:

1. Plan surgical approach so that it is perpendicular to the physis.

2. Exposed plate should be exposed to stand out in profile - can undermine more on metaphyseal side.

3. Remove all cortical bone. If cortical bone still presents, there may be fenestrations in the plate with multiple osseous bridges.

4. Younger individuals must anchor artificial material in the epiphysis with transepiphyseal screw.

5. Need dental mirror to visualize all of the physis.

6. If bridge reforms it can be resected a second and possibly even a third time.
7. Can do concomitant osteotomy with bridge resection. Can expect up to 15 degrees varus or valgus angulation correction.

8. Problems and complications.
   a. An injured physis may close earlier.
   b. Fractures can occur late through the metaphyseal defect created with surgery.
   c. Difficulty to stabilize the distal femoral osteotomy.

Acknowledgements

The author would like to acknowledge the permission granted for the following figures:

Figures--1 and 2

Figure 4--
Peterson HA: Physeal and Apophyseal Injuries Chapter 6 in Fractures in Children Vol III. Rockwood CA jr Wilkins KE Beaty JH Lippincott-Raven,Philha.Pa. 1996 (Fig. 6-3 p105).

Figure 5---
Peterson HA: Physeal and Apophyseal Injuries Chapter 6 in Fractures in Children Vol III. Rockwood CA jr Wilkins KE Beaty JH Lippincott-Raven,Philha.Pa. 1996 (Fig. 6-6,6-7 pp 106-107).

Figure 6--

Figure 7---
Peterson HA: Physeal and Apophyseal Injuries Chapter 6 in Fractures in Children Vol III. Rockwood CA jr Wilkins KE Beaty JH Lippincott-Raven,Philha.Pa. 1996 (Fig. 6-8 pp 107).

Figures 10,11 and 12